NPIC/P&DS/D/6-1349
6 May 1966

MEMORANDUM FOR: Deputy Chief, Development Branch, Plans and Development Staff

SUBJECT: Supplement to [redacted] 25X1

1. [redacted] has submitted a supplemental report and other documentation in support of their Feasibility Report on a Multiple Image Integration Printer. The supplement contains the graphs and the answers to questions requested by the Project Monitor on 11 February 1966. [redacted] also answered additional questions at a meeting with the Project Monitor at NPIC on 26 April 1966. 25X1

2. The graphs indicate that the transfer function of the proposed printer at 12X magnification is comparable to the results obtained with a typical high quality enlarger at 12X magnification. Graphs are presented for film type 3404, 3401, and tri-X; they indicate that some improvement in resolution can be obtained in coarse grained film but very little improvement in resolution from high definition film. An important point is brought out in Figure 10, the threshold of perception is greatly improved on tri-X for the integrated inputs over the single input. This is also emphasized again in the step wedges of Figure 11.

3. Attachment 3 is a copy of an article that was written in 1959 and published in the Journal of SMPTE, September 1965. This article pretty well substantiates the Image Dissector-Follow Spot technique that is proposed by [redacted] The last paragraph of the article also dwells on the slow scanning procedure that [redacted] would use in the print out mode. 25X1

4. Other points that were brought out in the report or the meeting are:

a. The limiting resolution for input materials is about 100-150 lines/mm. Any attempt to increase the resolution would require a decrease in input size and an increase in magnification to the CRT.

b. The video bandwidth will be 20 megacycles per second since the slow scan print out technique will be used and the 30 frame per second display rate will not have to be maintained.

c. The Image Integration Printer will not appreciably increase resolution but it will improve the information content by improving the contrast of low contrast images, reveal image detail in shadows or low contrast areas by superimposition of images from various missions, and by detecting change in several missions.

d. The main function of the instrument is as a printer and not as a viewer, therefore, the flicker display rate will not be a major factor as it was in the [redacted] contract. 25X

e. There will be 10 steps of contrast as explained in the report, the computation in the earlier report was based on high contrast and only two steps were used to indicate the maximum effect.

f. Illumination is not a problem when the follow spot technique is used.

g. The time to produce a slow scan print out is approximately one second.

5. All the questions have been answered satisfactorily by [redacted] 25X
and the state-of-the-art appears to have made major advances since
X1 the days of the [redacted] contracts. All indications are that
X1 the instrument proposed by [redacted] will be a useful instrument for the integration of grain limited images by increasing the signal-to-noise ratio.

X1 6. [redacted] estimates that it can produce a working instrument with the remaining funds. It is recommended that the Office of Logistics be instructed to establish a new completion date and authorize [redacted] 25X
to proceed with the fabrication of the instrument.

7. Attachment 2 contains changes that [redacted] proposed for an 25X
incentive type contract covering Phase II. It is recommended that the proposed changes in the incentive contract be rejected. The feasibility study shows that a signal-to-noise ratio of 1.7 is possible and that a maximum resolution of 130 lines may be achieved. The incentive targets they recommend are almost sure of achievement.

[redacted] 25X
Development Branch, P&DS

Attachments:

X1 1 - [redacted]
X1 2 - [redacted] Letter Dated 8 December 1965
X1 3.- Article from J. of [redacted], dated September 1965
X1 4 - [redacted] Supplement Report

Distribution:
Orig & 1 - Addressee
1 - Ch/DB
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1 - Project File (99848-5)
2 - DB Chronos

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growth and dissipati... produced by nuclear and large-scale high-explosive bursts. Because it is a point-by-point method, a large amount of computation is necessary to obtain the required amount of information. Much of this computation is repetitious, so that electronic computer techniques are de-sirable. ... film measurements and automatic plotting of the resulting coordinates will also greatly reduce the amount of effort involved.

It is hoped that the rectification method outlined here will find use in other fields where oblique photographs ... utilized to obtain the required information.

References

1. *Effects of Nuclear Weapons*, Atomic Energy Commission, U.S. Government Printing Office, Washington, D.C., 1960.
2. *Manual of Photogrammetry*, 2nd ed., American Society of Photogrammetry, Washington, D.C., 1952.

Attachment 3

On a Novel Application of the Image Dissector

By G. PAPP

The combination of an image dissector and a flying-spot scanner has advantages over either of these two devices alone. The combination requires much less average illumination than the image dissector used alone, and the combination has higher resolution, less noise, and less stringent phosphor decay requirements than the flying-spot scanner alone.

As is well known, in the image dissector the electronic image of the scene to be televised is scanned magnetically over a small aperture in the focal plane so that photoelectrons released by different picture elements of the scene enter the aperture of the electron multiplier in time sequence. In any particular instant the operation of the dissector can be compared to that of a flying-spot scanner, as shown in Fig. 1, (a) and (b).

If at the instant of scanning a particular target element dA, the light flux $d\Phi$ received by dA is equal in (a) and (b) and, if the same lens arrangement is used, the light flux $d\varphi$ utilized will be identical in the two cases. The same will be true of the outputs of the electron multipliers if the photosensitivity of the two detectors, as well as the gain of the two electron multipliers, is the same. Since this mutual correspondence exists at every instant, the two systems are identical as far as performance is concerned.

Although the outputs of the two systems are identical, a great difference exists in establishing the conditions postulated for this correspondence. Whereas in case (a) the target element dA is illuminated by the flux $d\Phi$ during the total frame time T, the same element is illuminated only for the elemental time Δt in (b). The average illumination in (b) is only a very small fraction, $\Delta t/T$, of the constant illumination used in (a). Thus, the result of the comparison of the two nonstoring camera systems, the dissector and the flying-spot scanner, is identical to the result of comparison between nonstoring and storing cameras: the dissector requires larger average scene illumination by a factor of $T/\Delta t$ than a comparable storing device or a flying-spot scanner.

Resolution Characteristic

In spite of this shortcoming there is a particular characteristic in which the image dissector surpasses all known camera tubes, namely its resolution. All other camera tubes and flying-spot scanner systems use a cathode-ray beam to perform the scanning operation or to illuminate the flying spot. Definition of a cathode-ray beam is never as sharp and exact as the direct imaging of an electronic image, as in the dissector or in an image converter tube. Measurements on a conventional image converter tube (IC 16) with transparent phosphor showed a resolution of 140 line pairs/mm which is equivalent to 280 TV lines/mm. In principle, comparable resolution could be achieved in the case of the image dissector, if the mechanical aperture were fine enough.

Mechanical apertures can be made small enough in size to satisfy all practical resolution requirements. An aperture $\frac{1}{2}$ mil square would give sufficient resolution to resolve 6,000 TV lines/diameter on a 3-in. diameter tube. With the conventional dissector techniques at high scanning rates, however, this is not achievable, due to limitations connected with the method of cathode illumination.

In continuous operation, present-day translucent photocathodes can be loaded up to an average photocurrent density of about 20 μamp/sq in. Higher average current density results in a permanent reduction of the photosensitivity of the cathode.

In dissector tubes, with defining apertures 30 mil square, the influence of this maximum current density limit is insignificant, since a light level well below the maximal illumination is sufficient for all practical cases. This is not so with small apertures. At a current density of 20 μamp/sq in., a 3-mil-square aperture, having an area of 9×10^{-6} sq in., results in a current of $i = 1.8 \times 10^{-10}$ amp entering the electron multiplier.

In scanning a 2 by 2 in. area in $\frac{1}{30}$ sec, the average scanning time Δt of each picture element is $\Delta t = \frac{3}{4} \times 10^{-7}$ sec. The amount of charge collected from every picture element is, consequently, $Q = 1.35 \times 10^{-17}$ coulomb, or $N = 84$ electrons, a comparatively small number, which is subject to statistical fluctuations having a root-mean-square value $\Delta N = \sqrt{N} = 9$. Disregarding the additional fluctuation introduced by the electron multiplier, the signal-to-noise ratio of the output signal will be $N/\Delta N = \sqrt{N}$.

Although the maximum illumination ... square aperture gives an acceptable current, the limitation is

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Posthumous paper, originally written May 1959; Dr. Papp was with ITT Industrial Laboratories, Division of International Telephone and Telegraph Corp., Fort Wayne, Ind.; submitted April 30, 1965.

prohibitive for a 1-mil-square aperture. The result of a similar calculation for this case is that the average number of electrons from each picture element is $N = 1$, for which the statistical fluctuation is also $\Delta N = 1$.

The rapid decrease of N from 84 to 1 is understandable because, as is well known for a fixed frame time, a decrease of the linear dimensions of the aperture by a factor n decreases the output signal by a factor n^4. If j_m is the maximum allowable current density and a the aperture size, per picture element a maximal current $j_m a$ and a charge $j_m a \Delta t$, that is, $N = j_m a \Delta t/e$ electrons can enter the multiplier. But $\Delta t = Ta/A$, if T is the frame time and A the picture area on the cathode. Thus

$$N = j_m \frac{T}{e} \frac{a^2}{A},$$

or for a given frame time and cathode area, N is proportional to a^2, i.e., to the fourth power of the linear aperture dimension, and the signal-to-noise ratio $\sqrt{N}$ is proportional to the square of that dimension. Any desirable improvement in the resolution is consequently accompanied by an intolerable decrease in the signal-to-noise ratio of the device. To overcome this limitation, means must be found to increase the current into the electron multiplier.

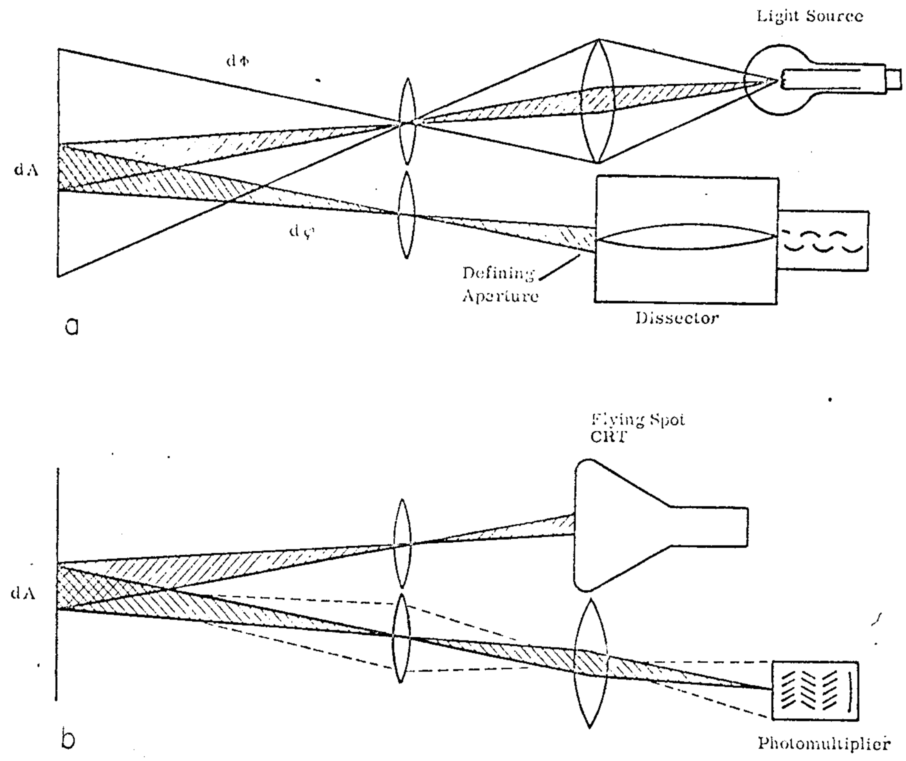

Fig. 1. Comparison of image dissector and flying-spot scanning systems.

Image Dissector with Flying-Spot Illumination

The situation can be greatly improved by using the image dissector in conjunction with a comparatively low resolution flying-spot illumination source. Instantaneous illumination of the scanned target element can be increased by a considerable factor. Assume, for example, that the flying spot illuminates an area K^2a on the cathode, moving in registry with the scanning. But this registry need not be very accurate—like the spotlight which illuminates an actor on a stage, which on the average, but not at every instant, has to follow the actor's motion. The formula found above for N still stands, but, since the illumination now has a duty cycle of K^2a/A, the permissible current density is A/K^2a times larger. Thus, if we still use the notation j_m for the value of 20 μamp/sq in., we now find

$$N = j_m \frac{T}{e} \frac{a}{K^2}$$

The improvement in N over the dissector formula, A/K^2a, amounts for a 1-mil aperture, a 2 by 2-in. picture and $k = 10$ (i.e., a 10 by 10-mil flying spot) to 4×10^4, while the signal-to-noise ratio would go up by a factor 200. We could also express our result by stating that, if T and K were kept constant, N would be proportional to the square, and $\sqrt{N}$ directly proportional to the linear, aperture dimension. Although the continuous registration of the flying spot and the picture element scanned by the dissector may be a difficult problem, the combination of a moderately sharp flying spot and the image dissector may be the proper solution for many high-resolution imaging problems.

It has to be pointed out that although high-resolution flying-spot scanners exist, the requirements of flying-spot scanners for the combination arrangement just described are much less stringent. The picture definition is determined entirely by the image dissector, and exact spot size, decay time, etc., of the flying-spot illumination source are completely immaterial.

We also note that the requirements on accuracy of registry and light flux density in the flying spot are relaxed if a larger value of k is chosen, at a sacrifice in the resulting signal-to-noise improvement. Thus a parallel improvement of the flying-spot tube and the whole system, both in the geometry and the circuitry of the arrangement, is recommendable.

Radio Technique for Signal and Noise

In the above discussion, purely statistical methods are employed for signal and noise considerations. The same result can be achieved by the more familiar noise considerations of the radio technique.

In the dissector case the decrease of the (linear) spot size by a factor of n results in a decrease by a factor of n^2 in the signal current. According to the corresponding shot noise formula, the noise remains unchanged, since the decrease of i by a factor of n^2 is accompanied by an increase in the bandwidth (of the properly designed amplifier) by a factor of n^2. The signal-to-noise ratio is decreased consequently by a factor of n^2. In the case of the flying-spot scanner, a similar consideration shows that the decrease of the size of the flying spot by a factor of n (keeping k constant) is accompanied by a decrease of the signal-to-noise ratio by a factor of n, if the signal current i remains constant.

The discussion herein has been based on the assumption that the scanning of a frame has to be performed in the standard frame time, $T = \frac{1}{30}$ sec. For slow scanning the image dissector may serve as a high-resolution camera tube without the flying-spot arrangement.

Attachment 2

December 8, 1965

[redacted]

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[redacted]

Forwarded herewith are two (2) copies of a report entitled Multiple Image Integration Viewer/Printer. Three (3) copies of the report are also enclosed for the technical monitor.

This report summarizes the results of Phase I and sets forth the recommended design parameters for Phase II of the contract.

Secondly as referenced in the contract, we are outlining our recommendations for completing the performance incentive arrangements.

In addition to the cost incentive provision that is already provided for in the contract, we believe that there are three (3) criterion that could be used for quantitatively measuring the performance of the Multiple Image Integration Viewer/Printer that is to be constructed during Phase II. They are resolution, signal to noise improvement, and operating time; and methods for measuring and evaluating each are as follows:

1. Resolution

Limiting resolution of each channel will be measured by using a high contrast USAF resolution target placed in the input platen with the magnification set at maximum (12x) and with the gamma control set at 1.0. The output image will be recorded on film by the regular camera built into the system. The spatial frequency of the smallest target group in which the three bar pattern is visible in both orientations (contrast of about 3%) will be regarded as the limiting resolution. This measurement will be made on each channel and the average of these values used. The complete determination shall be made five times, and the average of the best three used for incentive purposes.

2. Signal to Noise Improvement

Signal to noise ratio will be measured using a low frequency (10 cycles per inch) low contrast symmetrical bar pattern with additive random noise covering a spatial frequency band up to at least 1000 cycles per inch. Three test patterns will be prepared having identical bar pattern but different samples of noise of the same signal to noise ratio.

Two output images will be recorded on film, (1) produced by 1 channel only, (2) produced by all 3 channels after alignment. The two images will be processed identically and then scanned with a microdensitometer. The signal to noise ratio of each image will be measured by taking the ratio of the amplitude of the basic square wave to the RMS amplitude of the noise. The noise improvement ratio is then:

$$\frac{\text{S/N ratio of 3 integrated images}}{\text{S/N ratio of single image}}$$

This determination shall be made five times and the average of the best three values taken for incentive purposes.

3. Operating Time

Operating time of the equipment is the elapsed time for a complete cycle of operation by a trained operator from insertion of the three inputs containing images of the same area of normal contrast and detail to the exposure of the output film. It does not include setup and warmup time of the equipment, or processing time of the film. The sequence of operation will be (1) Insert 3 film chips in platens, line up manually, and feed into viewing aperture, (2) Correlate the 3 images using superimposition controls as required, (3) Optimize video processing of viewed images, (4) Print out integrated image onto film. This test shall be made five times using different imagery and the average of the best three values taken for incentive purposes.

The ranges of incentive effectiveness and the fee weights that we feel would be equitable for both parties to the contract are outlined below:

Performance Characteristic	Range of Incentive Effectiveness		Impact on Target Fee
Operating Time	Minimum of Range	5 minutes	+ 1.%
	Target	10 minutes	0
	Maximum of Range	15 minutes	- 1.%
Resolution	Maximum of Range	120 1/mm	+ 2.%
	Target	80 1/mm	0
	Minimum of Range	60 1/mm	- 1.%

Performance Characteristic	Range of Incentive Effectiveness		Impact on Target Fee
Signal to Noise Ratio	Maximum of Range	1.5	+ 2.%
	Target	1.4	0
	Minimum of Range	1.3	- 1.%
Cost Incentive 80 Govt./20 Contractor			
	Underrun		+ 1.%
	Target		0
	Overrun		- 1.%

After application of the incentive arrangement upon completion of the contract, the final fee would in any event be subject to the limitations presently set forth in the contract which are:

Minimum fee	6% of target cost
Target fee	8% of target cost
Maximum fee	12% of target cost

The ranges of performance from the lower side up to "target" we have confidence will in themselves result in an item of equipment that will yield meaningful and valuable information in a relatively rapid thru-put time cycle. The performance goals set forth as "maximums" under the incentive arrangements, although realistic, cannot easily be attained within the present state of the art. To strive toward these goals during Phase II will be a challenging effort.

If you need any additional information, please don't hesitate to call; and in the meantime, we will await your authorization to proceed into Phase II.

Very truly yours,

25X1

Contracts Manager

AKM:mja

Enclosures

cc: Technical Monitor (with 3 copies of report) ✓